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The long term objective of this research was to understand the role of surface heat and salt fluxes in the formation of Arctic Ocean water masses. These processes are of paramount importance in high latitude regions, where the presence of sea ice and the interplay between heat and salinity fluxes create a complex thermohaline environment. Our research combined the analysis of both observed data and model output. We analyzed conductivity-temperature-depth data taken by both surface and submarine ships in order to assess the generation and circuilation of halocline waters in the Arctic Ocean. We also developed a numberical model of a summer lead in order to better parameterize melting processes in larger-scale simulations.

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Final Report

ONR Grant No. N000014-90-J-1227

Title: Studies of Air-Sea-Ice Interaction

Principal Investigator: **Michael Steele**

This grant sponsored research in the study of heat, salt, and momentum exchange at the surface of the Arctic Ocean. Both observational and modeling studies were performed.

Four papers were produced that concerned results from the Coordinated Eastern Arctic Experiment (CEAREX), an ONR-sponsored field project in the waters near Svalbard, Norway. Two of these (*McPhee and Steele*, 1990; *Steele and Morison*, 1992) focused on instrument calibration and two (*Steele and Morison*, 1993; *Steele et al.*, 1995) on geophysical observations and interpretation. I have also analyzed observational data from the SCICEX program (*Morison et al.*, 1997). Two papers concern modeling studies (*Steele*, 1992; *Steele et al.*, 1997).

In ***McPhee and Steele*** (1990) we examined turbulence statistics derived from two co-located instruments, Smart Acoustic Current Meters (SACM's) and Turbulence Clusters (TC's). We showed that the SACM's did a good job of measuring turbulence relative to the TC's. This was good news, since the former are autonomous and can thus be used on drifting buoys. We also showed a directional dependence which was related to roughness variations of the ambient ice floe.

In ***Steele and Morison*** (1992) we developed two methods to obtain vertical profile data from drifting SALARGOS (Salinity-ARGOS) buoys. The first was a five-step "non-parametric" smoothing algorithm that gives an unbiased salinity or temperature profile from the data. Briefly, the steps are: 1) averaging of data values at the same depth, 2) median smoothing to eliminate outliers, 3) depth-bin averaging, 4) interpolation to a regular vertical grid, and 5) running mean smoothing. The second was a nonlinear least-squares routine using a two-exponential formula that captures the sharp pycnocline as well as the more gradual deep stratification and the Atlantic layer. These routines are in use now as SALARGOS data from the Weddell Sea are analyzed.

In ***Steele and Morison*** (1993) hydrography from the CEAREX drift of a Salargos buoy across the Atlantic Inflow Current northeast of Svalbard was analyzed. Vertical cross-sections and T-S plots were created that showed a very warm, eastward-flowing core trapped near the 1000

m isobath. The pycnocline shoaled and sharpened in response to an intense local storm, and then relaxed back to "normal". Our analysis showed a sharp water mass transition between the deep Arctic Basin and the shallower Barents Sea continental shelf.

In ***Steele et al.*** (1995) the hydrographic analysis of the previous paper was extended by including CTD data taken over the course of several months. The CEAREX data showed that the so-called "cold halocline" layer of the Arctic Basin has its origins, at least in part, within the MIZ of the Barents Sea. The process involves heat loss to the cold atmosphere from warm Atlantic Water, in concert with the cooling and freshening that occurs as this water encounters the ice edge. Assuming this also occurs in the MIZ of the Fram Strait, the total amount of halocline water formed in this way is roughly 0.5 Sv, which is about 1/3 to 1/2 of that formed in polynyas by ice growth. Additionally, a new visualization technique was developed that allows the rapid identification of water masses in section format, using digital color-coding.

My observational work has continued in the analysis of SCICEX (SCientific ICe EXpeditions) data, collected by US Navy submarines during the 1990's. Our analysis of the SCICEX'93 hydrographic data (***Morison et al.***, 1997) indicates that upper halocline water may be forming close to or within the Makarov Basin, a region of the Arctic Ocean that has been virtually unexplored until SCICEX'93. The analysis also shows the classic "layering" of successive types of halocline waters as one moves cyclonically around the Arctic Ocean from Fram Strait. This work is continuing on a separate ONR grant focused on the SCICEX'95 cruise.

The first modeling paper (***Steele***, 1992) was an attempt to insert a measure of summertime ice floe geometry into a large-scale numerical model. The role of lateral melting was shown to be a significant fraction of total melt only for small floes (order 30 m in diameter). The simulations demonstrated the need for more information on floe diameter distributions, and showed that lateral melting may be 2-3 times more rapid than bottom melting for the same thermal forcing, due to the different behavior of buoyant melt water adjacent to vertical and horizontal ice surfaces. This work will continue on an NSF grant as part of the SHEBA project.

The second modeling paper (***Steele et al.***, 1997) examined a long-neglected subject: What makes sea ice move? In particular, we examined the spatial and temporal variations in the various terms of the sea ice force balance. Daily, weekly, monthly, seasonal and annual time scales were considered and contrasted. We found that over much of the Arctic Ocean, except in summer, the dominant balance on monthly and longer time scales was between air drag, water drag, and internal stress gradient. This was true even hundreds of kilometers away from the coasts, and even though the wind-ice motion correlation was high. Also, we found a strong sensitivity to the

internal stress parameter P*. And we found that the shear component of the internal stress gradient was large, which casts a strong doubt on the theoretical validity of the cavitating fluid model.

Much of this work is continuing, sponsored by ONR, NASA, and NSF.

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